

# A sample-oriented catalogue of BL Lacertae objects

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## ABSTRACT

We present a catalogue of 233 BL Lacertae objects compiled through an extensive bibliographic search updated to mid-1995. A large fraction of the sources listed in the catalogue belongs to well-defined samples and can be used for statistical purposes. A smaller fraction consists of miscellaneous (but confirmed) BL Lacs and of objects classified as BL Lac candidates. We discuss the selection criteria of the different samples, report the discovery of two previously unnoticed BL Lacs in the Palomar–Green survey, and comment on the possible association of some of the still unidentified high galactic latitude gamma-ray (EGRET) sources with BL Lacs. Some statistical properties of the catalogue are also briefly discussed.

**Key words:** catalogues – galaxies: active – BL Lacertae objects: general – Radio continuum: galaxies – X-rays: galaxies

## 1 INTRODUCTION

BL Lacertae objects are hard to find. This is simply due to one of their defining features: the almost complete lack of emission lines. As a result, contrary to most other astronomical sources, only a few objects of this class have been discovered at optical frequencies. About 95 per cent of known BL Lacertae objects have in fact been discovered in the radio or X-ray band, where they can be more easily recognized thanks to other distinguishing properties such as flat radio spectra and a distinctive multifrequency energy distribution. BL Lacertae objects are also intrinsically rare and constitute only a few per cent of the known population of active galactic nuclei (AGN).

The need for an up-to-date BL Lac catalogue came for a practical reason. We were studying the AGN content of the WGA catalogue (White, Giommi & Angelini 1994), a large catalogue of X-ray sources generated from all the *ROSAT* PSPC pointed observations. We wanted to extract from it all known BL Lacertae objects to analyse their X-ray properties, but, when we started using the Véron-Cetty & Véron (1993a) and Hewitt & Burbidge (1993) catalogues, we realized that the number of BL Lacs had recently increased in such a way as to require a new compilation. Also, the criteria according to which objects had been called BL Lacs in previous catalogues were highly inhomogeneous.

We then put together a list of BL Lacertae objects, taking a novel approach. Instead of assembling all objects ever called BL Lacs in the literature, we started from the (by now quite numerous) complete samples, adding at the end additional objects from existing catalogues and the literature. By *complete sample* here we mean an homogeneous set of sources detected in a *statistically well-defined* and *com-*

*pletely identified* survey (although in some cases the identification process is not yet 100 per cent complete). In most cases statistically well-defined means flux limited in one or more energy bands.

The result of this effort is a catalogue of 233 BL Lacs, i.e. significantly larger than the Véron-Cetty & Véron (171 BL Lacs) and Hewitt & Burbidge (90 BL Lacs) catalogues but above all, we believe, based on more homogeneous criteria. Most samples, in fact, adopt a classification based on equivalent width  $W_\lambda$ , 5 Å being the dividing line between BL Lacs and quasars. Although there are undoubtedly borderline objects, in which emission lines appear when the continuum is in a low state, this value seems to separate quite well the two classes (see discussion in Urry & Padovani 1995).

The structure of the paper is as follows: in Section 2 we describe the catalogue and in particular the samples on which it is mostly based, while in Section 3 we present some of the statistical properties of the catalogue.

## 2 THE CATALOGUE

The catalogue includes all objects from the BL Lac samples known to us at the time of writing (1995 June) plus objects listed in the Véron-Cetty & Véron (1993a) and Hewitt & Burbidge (1993) catalogues as follows: objects common to the two catalogues were included under the label ‘miscellaneous’; objects belonging to only one of the two were conservatively labelled ‘candidate’. This last group includes also BL Lac candidates belonging to complete samples or found in the literature. We have excluded from our list objects originally classified as BL Lacs or BL Lac candidates but which were later shown to have strong lines: examples

are 2201+044, included in the *HEAO-1* sample by Laurent-Muehleisen et al. (1993) but recently shown to be a Seyfert 1 galaxy (Véron-Cetty & Véron 1993b), and 1214+1753, a BL Lac candidate in Foltz et al. (1987) but a broad absorption line QSO in Stocke et al. (1992).

The catalogue, which is ‘complete’, to the best of our knowledge, as far as BL Lacs in samples and miscellaneous objects are concerned, is presented in Table 1. Column 1 gives the most common name(s), columns 2 and 3 the J2000 positions for each object. Columns 4, 5 and 6 give the redshift,  $V$  magnitude and radio flux at 5 GHz, while column 7 contains the references for these quantities. Finally, in column 8 we give references to X-ray data while in column 9 we report the sample(s) to which the object belongs or the ‘miscellaneous’ or ‘candidate’ classification (the latter followed, if applicable, by the name of the sample to which the object belongs). The data generally come ‘as given’ by the paper describing the sample or from the catalogues. When radio fluxes were not provided, we searched available 5-GHz radio catalogues at northern and southern declinations (Becker, White & Edwards 1991; Wright et al. 1994; Griffith et al. 1994, 1995), which at present reach  $\sim 20 - 40$  mJy. It can then be safely assumed that the 13 BL Lacs in this catalogue lacking radio data have 5-GHz radio fluxes below these limits. Positions are usually good to within a few arcseconds for the radio- and optically-selected sources. A similar accuracy is reached also by the X-ray-selected sources in the *Einstein* Imaging Proportional Counter (IPC) Slew survey, for most of which precise radio positions are given in Perlman et al. (1995b), in the *Einstein* Observatory Extended Medium Sensitivity Survey (EMSS), whose optical coordinates have been taken from Maccacaro et al. (1994), and in the *ROSAT* all-sky survey (RASS), whose BL Lacs have optical coordinates (Bade, Fink & Engels 1994). We also present here previously unpublished radio positions, good to within  $1 - 2$  arcsec, for the following *EXOSAT* BL Lacs: EXO0706.1+5913, EXO0811.2+2949, EXO1004.0+3509, EXO1118.0+4228, EXO1146.9+2455, and EXO1811.7+3143. In a few cases accurate radio positions were obtained from the NASA/IPAC Extragalactic Database (NED). In summary, coordinates are uncertain up to a few tens of arcseconds only for four *EXOSAT* BL Lacs (EXO0044.4+2001, EXO0423.4-0840, EXO0556.4-3838, and EXO1415.6+2557), one *HEAO-1* BL Lac (1H 0829+090, plus 1H 1914-194, for which coordinates are not available), and the five new RASS BL Lacs published by Brinkmann et al. (1995). In cases when an object belongs to more than one sample, the most accurate coordinates are quoted.

One of the characteristics of BL Lacs is their strong variability, which generally increases with frequency. While this is not a problem in the radio band where large-amplitude variability is rare (e.g. Miller & Wiita 1991),  $V$  magnitudes should be taken with care. As regards the 1-Jy BL Lacs, however, we provide values which should be quite representative of the ‘typical’ state of the objects, from Padovani (1992). The reader is referred to that paper for a description of the derivation of these magnitudes and for the appropriate references. We also note that optical monitoring data for many BL Lacs are available in the literature (e.g. Pica et al. 1988; Webb et al. 1988; Falomo, Scarpa & Bersanelli 1994).

Given that a number of additional complications are

present in the X-ray data (different instruments and bands, uncertainties in the spectral indices, photoelectric absorption), we do not provide X-ray fluxes. We prefer instead to give at least one reference, so that X-ray data can be easily retrieved. X-ray references have been compiled as follows: our main sources were the catalogue of Della Ceca et al. (1990), a compilation of X-ray data up to 1986, and the catalogue of X-ray spectra of Ciliegi, Bassani & Caroli (1993), complete up to the end of 1991. We also refer to the recent WGA catalogue of *ROSAT* PSPC sources (White et al. 1994), while in the case of X-ray-selected objects we refer to the original papers describing the sample. Finally, for those sources not included in the above-mentioned catalogues, we first performed a literature search and then searched the *Einstein* IPC and *EXOSAT* databases. At the end of this process, 30 objects (or about 13 per cent of the catalogue) had no X-ray references. Considering only confirmed BL Lacs this number goes down to 10 (or about 5 per cent of the confirmed objects).

The catalogue breaks up into the following sub-classes: confirmed BL Lacs in samples (159 objects or 68 per cent of the catalogue), miscellaneous BL Lacs (24 objects or 10 per cent of the catalogue), and BL Lac candidates or objects whose BL Lac classification is still uncertain (50 objects or 22 per cent of the catalogue), for a total of 233 objects.

We now describe the various samples and classes, grouping them into wavelength bands.

## 2.1 Radio surveys and catalogues

The radio band is where the class of BL Lacertae objects was discovered. For many years the great majority of the BL Lacs known were found among the sources detected in large radio surveys. As a consequence, all the classical and well-studied objects have been discovered at these frequencies.

### 2.1.1 The 1-Jy sample

This is currently the largest complete radio sample of BL Lacs. Described in Stickel et al. (1991) and Stickel, Fried & Kühn (1993), it includes 34 objects extracted from the 1-Jy catalogue (radio flux  $f_r \geq 1$  Jy at 5 GHz: Kühn et al. 1981a), a flux-limited catalogue which covers essentially the whole sky excluding the galactic plane ( $|b| < 10^\circ$ ) and the Magellanic Clouds, according to the following criteria: (1) flat radio spectrum between 2.7 and 5 GHz ( $\alpha \leq 0.5$ ,  $f_\nu \propto \nu^{-\alpha}$ ); (2) magnitude brighter than 20; (3) emission lines in the optical spectrum absent or weak with a rest-frame equivalent width of the strongest line  $< 5$  Å. Three more objects are included in the updated version of the 1-Jy catalogue (Stickel, Meisenheimer & Kühn 1994). Two of these have  $V \geq 20$ , while the third one (PKS 2149+173) has  $V = 18.9$ , although during the period of the spectroscopic observations it was below the 20th magnitude limit (Stickel & Kühn 1993a). PKS 0521-365, an object classified as a BL Lac in the literature but originally excluded from the 1-Jy sample because some of its lines had  $W_\lambda > 5$  Å, has been included as an uncertain BL Lac, since its [O III] luminosity is more typical of BL Lacs than of quasars (see discussion in Urry & Padovani 1995).

Brunner et al. (1994) have reported on a *ROSAT* observation of S5 0454+844 (which belongs both to the 1-Jy and

S5 samples), which shows the BL Lac object to be only 48 arcsec away from a source about five times brighter. They therefore suggest that previous reports of X-ray emission from this object (which are referred to in Table 1) could be due to a misidentification.

It has been suggested (Perlman et al. 1995a) that the requirement on the radio spectral index ( $\alpha_r \leq 0.5$ ), imposed as a criterion for the selection of the 1-Jy BL Lacs to exclude the bulk of the radio galaxies, might have resulted in the loss of some objects, since BL Lacs with steeper radio spectral indices are known. To estimate the magnitude of this effect, we performed the following simple calculation: out of the 119 confirmed BL Lacs which, to our knowledge, have 2.7–5 GHz spectral index information, only 8 have  $\alpha_r > 0.5$ . Out of these, one (S5 1749+701) was included nevertheless in the 1-Jy sample because the steep radio spectrum was clearly due to variability and non-simultaneous measurements (Stickel et al. 1991). As regards the remaining ones, variability cannot be the explanation for the steepness of  $\alpha_r$  in the case of PKS 0548–322, MS1207.9+3945 and MS1402.3+0416 since the multifrequency radio measurements were contemporaneous (Stoeckle et al. 1985), while it cannot be excluded in the remaining four objects, ON 231, MS1407.9+5954, RXJ00079+4711 and RXJ16442+4546. We then estimate that, out of the 85 BL Lacs not included in the 1-Jy, S4 and S5 samples (which were selected to have flat radio spectra), between 3 (4 per cent) and 7 (8 per cent) have 2.7–5 GHz spectral indices steeper than 0.5. This suggests that the condition requiring a flat radio spectrum might cause the loss of only 1 to 3 BL Lacs in the 1-Jy sample.

### 2.1.2 The S4 sample

The S4 sample includes 14 objects extracted from the S4 catalogue ( $f_r \geq 0.5$  Jy at 5 GHz,  $35^\circ \leq \delta \leq 70^\circ$  and  $|b| \geq 10^\circ$ : Pauliny-Toth et al. 1978; Stickel & Kühr 1994) by Stickel & Kühr (1994) using the same criteria as those applied to 1-Jy BL Lacs. Note that S4 1652+398 (Mrk 501) and S4 1823+568 have been mistakenly classified as a normal galaxy and a QSO respectively in Stickel & Kühr (1994): both are in fact confirmed 1-Jy BL Lacs. About 10 per cent of the S4 sources are still classified as empty fields so a small number of BL Lacs could still be unidentified.

### 2.1.3 The S5 sample

The S5 sample includes 13 objects extracted from the S5 catalogue ( $f_r \geq 0.25$  Jy at 5 GHz,  $\delta \geq 70^\circ$  and  $|b| \geq 10^\circ$ : Kühr et al. 1981b) by Kühr & Schmidt (1990). The selection criteria are slightly different from those adopted for the 1-Jy and S4 samples: they include in fact maximum optical polarization  $P_{\max}$  larger than 3 per cent on at least one occasion, while it is not clear what is the equivalent width limit adopted to separate BL Lacs from quasars. (Note that all but two 1-Jy BL Lacs have  $P_{\max} > 3$  per cent [Stickel et al. 1994], although this was not one of the selection criteria.) We have excluded S5 1053+81 from the sample because its spectrum shows emission lines (Xu et al. 1994), and we have added a BL Lac candidate, S5 2353+81 (Stickel & Kühr 1993b). The S5 catalogue is currently being updated by Stickel & Kühr (in preparation).

We note that the dynamical range of source flux in radio surveys is small and of order  $\approx 10$ . This demonstrates that

the study of BL Lacs is still at a very early stage even in the part of the electromagnetic spectrum where these objects were first discovered more than 25 years ago.

## 2.2 Optical surveys and catalogues

Several surveys that make use of various detection methods have been carried out in the optical band. Some of these have been tuned to the search for BL Lacs. However, despite the large efforts only a handful of BL Lacs have so far been discovered at these frequencies.

### 2.2.1 The Palomar–Green sample

The Palomar–Green (PG) sample covers 10714 deg<sup>2</sup> of sky down to an average limiting magnitude  $B = 16.1$  for  $U - B < -0.46$  (Green, Schmidt & Liebert 1986). Four BL Lacs were initially identified in the catalogue: OJ 287, OQ 530, PG 1553+113, 1H 1219+301 (2A 1219+305), the last object not belonging to the complete sample. Three more objects, originally misclassified as white dwarfs, were discovered by Fleming et al. (1993) by cross-correlating the PG white dwarf list with the RASS. To check if there were other known BL Lacs still lurking in the catalogue we cross-correlated the PG sample with the present BL Lac catalogue. Much to our surprise, we found that Mrk 421 was only about 51 arcsec away from PG 1101+385 and PKS 2254+074 was about 9 arcsec away from PG 2254+074, the former being classified as a ‘composite spectrum object’ in Green et al. (1986), the latter, which does not belong to the complete sample, being unclassified. While an offset of 9 arcsec is consistent with the typical accuracy of the PG positions (about 8 arcsec in each coordinate), the larger deviation of 51 arcsec could be due to the fact that Mrk 421 is an extended object. Indeed, an examination of the charts in the PG catalogue shows that PG 1101+385 coincides with Mrk 421 (R. Green, private communication). The total number of BL Lacs in the PG sample is then 9 objects, of which 7 belong to the complete sample. We cannot exclude the possibility that other BL Lacs are present in the sample awaiting discovery. The PG sample gives only a lower limit to the number of optically selected BL Lacs, since many such objects have  $U - B$  colours above the selection limit: using the colours tabulated in Véron-Cetty & Véron (1993a) and Hewitt & Burbidge (1993), to derive the  $U - B$  distribution of known objects, we estimate that the PG sample misses about 40 per cent of BL Lacs.

### 2.2.2 The optical variability sample

A survey of optically variable quasars over 18 deg<sup>2</sup> was carried out by Hawkins et al. (1991). This led to the discovery of two BL Lacs brighter than  $B \sim 19$ ; some more could be present in the field.  $V$  magnitudes for the two objects have been derived from their mean  $B$  magnitudes and  $B - V$  colours.

### 2.2.3 The optical polarization survey

An optical polarization survey covering 560 deg<sup>2</sup> of high galactic latitude sky was carried out by Jannuzi, Green & French (1993). Only one BL Lac candidate was found and

the conclusion of this work was that most BL Lacs are not highly polarized (e.g. they do not spend much time at  $P_{\max} \gtrsim 30$  per cent) and that much higher sensitivities in polarization levels are needed to detect a significant number of new BL Lacs.

### 2.3 X-ray surveys and catalogues

Over the past few years several X-ray surveys have become available and many new BL Lacs have been discovered. Thanks to their strong X-ray emission, selection in this band has become the most effective way of discovering new BL Lacs. At present more than 50 per cent of the BL Lacs known have been discovered at X-ray frequencies.

#### 2.3.1 The EMSS sample

The EMSS (Gioia et al. 1990; Stocke et al. 1991; Maccacaro et al. 1994) is a flux-limited sample of X-ray sources discovered serendipitously in 1435 *Einstein* IPC fields centred on high-latitude ( $|b| > 20^\circ$ ) targets. It covers  $780 \text{ deg}^2$  in the  $0.3 - 3.5 \text{ keV}$  band and goes down to  $f_x \sim 5 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ , albeit in a much smaller area since the area of sky covered is a strong function of X-ray flux (see table 5 of Gioia et al. 1990).

The EMSS includes 34 BL Lacertae objects [plus two BL Lac candidates, which is one less than in the original list, since MS1332.6–2935, a BL Lac candidate in Stocke et al. (1991), is now a confirmed BL Lac (Perlman et al. 1995b)], selected according to the following criteria: *observed* equivalent width of any emission line  $< 5 \text{ \AA}$  and evidence for dilution of starlight in the spectrum by a non-thermal continuum, which in practice means a Ca II break with a relative flux depression blueward across the break  $\leq 25$  per cent in the spectra (normal ellipticals would have values around 50 per cent). Note that, although the equivalent width division is the same as the one applied to the 1-Jy and S4 BL Lacs, here it refers to the *observed* and not to the *rest-frame* value. It then follows that, since  $W_{\lambda, \text{rest}} = W_{\lambda, \text{obs}}/(1+z)$ , the EMSS could classify as AGN some objects that would have been considered as BL Lacs by the 1-Jy sample, especially at high redshifts.

Browne & Marchã (1993) have suggested that the EMSS might misclassify some low-luminosity BL Lacs whose light is swamped by the host galaxy, which is typically a bright elliptical. Padovani & Giommi (1995a), within their hypothesis on the relationship between X-ray- and radio-selected BL Lac objects, have performed numerical simulations to establish the incompleteness level of the EMSS implied by the Browne & Marchã effect. By applying the prescription of Browne & Marchã to establish if a BL Lac is recognized as such or if it is misclassified, they found that about 10 per cent of the EMSS BL Lacs could be lost. Perlman et al. (1995a) have also discussed this effect and looked for possible misidentifications of BL Lacs with clusters of galaxies, coming up with one possible BL Lac (MS1019.0+5139) and four other (unlikely in their view) possibilities. We note that PKS 2316–423 (MS2316.3–4222), classified as a cluster of galaxies by Stocke et al. (1991), has recently been suggested to host a BL Lac object by Crawford & Fabian (1994).

Complete BL Lac subsamples from the EMSS have been presented by Morris et al. (1991) and Wolter et al. (1994).

#### 2.3.2 The EXOSAT sample

The *EXOSAT* High Galactic Latitude Survey (HGLS: Giommi et al. 1991) is a flux-limited sample of X-ray sources discovered serendipitously in 443 Channel Multiplier Array (CMA) fields centred on high-latitude ( $|b| > 20^\circ$ ) targets. It covers  $783 \text{ deg}^2$  in the  $0.05 - 2.0 \text{ keV}$  band and goes down to  $f_x \sim 2 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ , albeit in a much smaller area since the area of sky covered is a strong function of X-ray flux (see fig. 1 of Giommi et al. 1991).

The *EXOSAT* HGLS includes 12 BL Lacertae objects (plus two BL Lac candidates) selected according to criteria similar to those of Stocke et al. (1991).

#### 2.3.3 The HEAO-1 sample

The *HEAO-1* Large Area Sky Survey (LASS, also known as *HEAO A-1*) has produced a catalogue of bright, hard X-ray ( $0.8 - 20 \text{ keV}$ ) sources over the entire sky (Wood et al. 1984). The optical identification programme is still on-going and the final BL Lac sample has not been published yet. Schwartz et al. (1989) have presented some preliminary results, while Laurent-Muehleisen et al. (1993) have published a list of 29 *HEAO-1* BL Lacs, one of which (2201+044) is now known to be a Seyfert 1 galaxy (Véron-Cetty & Véron 1993b). PKS 0521–365, previously discussed, has been included in our list as an uncertain BL Lac.

Although it is not entirely clear what were the precise criteria for the classification as BL Lacs, it is known that the *HEAO-1* BL Lacs have been selected on the basis of their UV excess (Schwartz et al. 1989). This means that the *HEAO-1* sample suffers from the same incompleteness as the PG sample, discussed above (Section 2.2.1).

Laurent-Muehleisen et al. (1993) give positions only for a subsample of their objects. This was not a problem for the majority of the remaining sources, since they are in common with other samples (Slew, 1-Jy). In one case (1H 0829+089) positions were derived from a search in radio catalogues around the IAU position (i.e. the position obtained from the source name) and therefore the coordinates are only good to within a few tens of arcseconds. In another case (1H 1914–194) no radio source was found within a degree from the IAU position, so no coordinates are available for this object.

#### 2.3.4 The Slew survey sample

The IPC Slew survey has been constructed using the *Einstein* ‘slew’ data taken when the satellite was moving from one target to the next (Elvis et al. 1992), and covers a large fraction of the sky with sensitivities  $\sim 5 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ , reaching a flux limit  $f_x \lesssim 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  over a much smaller fraction of the sky (Schachter, Elvis & Szentgyorgyi 1993b).

Perlman et al. (1995b) (see also Schachter et al. 1993a) have presented a sample of 62 BL Lacs (which include 2 probable BL Lacs) extracted from the Slew survey adopting the same classification criteria as the EMSS survey. This is the largest BL Lac sample so far. Out of these objects, a complete sample of 48 BL Lacs has been defined. Six more objects have not been observed spectroscopically but have broad-band energy indices typical of BL Lacs and have been included here as BL Lac candidates. To these we also add

1ES1249+174W, discussed by Perlman et al. (1995b).

The *HEAO*-1 and the Slew surveys include many BL Lacs previously selected in radio surveys. This shows a severe limitation of a classification that has been frequently used in the recent past, based solely on the selection band. This classification divides the class of BL Lacs into *X-ray-selected* (or XBL) and *Radio-selected* (or RBL) depending on the band where the object was discovered: a number of objects could therefore be classified as both XBL and RBL. To overcome this difficulty Padovani & Giommi (1995a) have proposed to classify the objects on the basis of the ratio between the X-ray and radio fluxes (a parameter which univocally identifies an object) and suggested a division into ‘RBL-like’ or low-energy cutoff BL Lacs (LBL) and ‘XBL-like’ or high-energy cutoff BL Lacs (HBL). This division corresponds in fact to a break in their broad-band spectrum at infrared/optical frequencies for the former objects and at ultraviolet/X-ray energies for the latter.

### 2.3.5 The RASS sample

The *ROSAT* all-sky survey (RASS; Voges 1992) includes about 60000 X-ray sources, several hundred of which should be BL Lacs. The identification programme will inevitably take several years but early results have started to appear in the literature. Bade et al. (1994) report the discovery of 10 new BL Lacs through follow-up spectroscopy of AGN candidates detected in the RASS survey. Three of the objects are in common with the Slew survey. All optical spectra satisfy the EMSS BL Lac criteria of Stocke et al. (1991). Brinkmann et al. (1995), quoting a private communication from A. Kock, present five more new RASS BL Lacs which are (mostly) included in the 5-GHz survey of Condon, Broderick & Seielstad et al. (1989). Since no coordinates were given, we obtained them from the radio catalogue, searching near the coordinates obtained from the source name: they should therefore be accurate only to within a few tens of arcseconds. In one case (RXJ16264+3513), the radio source does not belong to the 5-GHz catalogue and therefore no coordinates are available.

### 2.3.6 The WGA and ROSAT SRC catalogues

Two catalogues of *ROSAT* sources detected during pointed observations have recently become available: the WGA catalogue (White et al. 1994) and the ROSAT SRC catalogue (Voges et al. 1994). These catalogues cover about 10 per cent of the sky with a much higher sensitivity than that of the RASS survey. Both catalogues include 50000 – 60000 X-ray sources and probably a few hundred BL Lacs. Identification of these sources has just begun. Wolter et al. (in preparation) report the discovery of one BL Lac and two BL Lac candidates. Giommi et al. (in preparation) also report the identification of a WGA source with a BL Lacertae object.

## 2.4 Gamma-ray catalogues

The detection of a few BL Lacs at energies  $\gtrsim 100$  MeV by the Energetic Gamma Ray Experiment Telescope (EGRET) on the *Compton Gamma Ray Observatory* (CGRO; Gehrels, Chipman & Kniffen 1993) has been reported recently (Fichtel et al. 1994). So far, only previously known BL Lac objects have been associated with  $\gamma$ -ray sources, five at a high

confidence level ( $> 5\sigma$ ), four (including the uncertain BL Lac PKS 0521–365) at a lower (between  $4\sigma$  and  $5\sigma$ ) confidence level, and one (PKS 2155–304) for which the confidence level is not yet available (Vestrand, Stacy & Sreekumar 1995). (One of the five sources detected with a high confidence level, S4 0954+658, has been detected only during phase 2 of the EGRET observations [Mukherjee et al. 1995] and therefore is not included in the EGRET phase 1 catalogue of Fichtel et al. 1994. This also applies to PKS 2155–304). A cross-correlation of our BL Lac list with the EGRET catalogue shows that some high-latitude marginal detections, still unidentified, might be associated with BL Lacs (some of these are also described in the notes to table 11B in Fichtel et al. 1994). These include: 3C 66A, which is 52 arcmin away from GRO J0222+42 (with which it had been previously identified), which has a 95 per cent error radius of 47 arcmin; MS1312.1–422, only 17 arcmin away from GRO J1314–42, with an error radius of 71 arcmin. This is classified as a ‘possible’ identification by Fichtel et al. (1994), probably because its relatively low radio flux (18.5 mJy at 5 GHz) would make it the extragalactic object with the largest  $\gamma$ -ray-to-radio flux ratio (all the other sources, in fact, have 5-GHz radio fluxes typically larger than 1 Jy). We note, however, that within the 95 per cent error radius of GRO J1314–42 there are about 10 unclassified radio sources with  $f_r \gtrsim 50$  mJy in the Parkes-MIT-NRAO (PMN) Southern survey (Wright et al. 1994), three of which have  $f_r > 100$  mJy. It is therefore likely that the counterpart of the  $\gamma$ -ray detection is one of the brighter PMN sources. PKS 2032+107 is 89 arcmin away from GRO J2039+11, with an error radius of 66 arcmin, while PKS 2029+121 is somewhat more distant, at 110 arcmin. Both objects have 5-GHz radio fluxes around 1 Jy. PKS 2149+173 is 86 arcmin away from GRO J2157+18, with an error radius of 47 arcmin, while the flat-spectrum radio quasar PKS 2201+171 is offset by 99 arcmin. Again, both objects have 5-GHz radio fluxes around 1 Jy. The BL Lac candidate 1ES1745+504, with a 5-GHz radio flux as small as 1.3 mJy, was found to be 62 arcmin away from GRO J1742+49, with an error radius of 93 arcmin. However, a much more likely identification is that of the flat-spectrum radio quasar S4 1738+499, offset from the  $\gamma$ -ray source by 33 arcmin and with a 5-GHz radio flux of 0.6 Jy. Finally, a few BL Lacs are relatively near, although still outside the 95 per cent error circle, to  $\gamma$ -ray sources mostly identified with radio quasars. In some of these cases part of the  $\gamma$ -ray emission might be due to the BL Lac.

## 2.5 Miscellaneous objects

Twenty-four objects have been classified as BL Lacs both by Véron-Cetty & Véron (1993a) and by Hewitt & Burbidge (1993) but do not belong to any BL Lac sample. The reality of their classification has been recently confirmed by Véron-Cetty & Véron (1993b) for six of them: PKS 0047+023, PKS 0301–243, PKS 0808+019, PKS 1604+159, PKS 1717+177 and PKS 2254–204. We have no reason to suspect that the remaining objects would not satisfy the criteria adopted in the definition of most BL Lac samples.

Five sources (PKS 0406+121, PKS 0422+004, PKS 0754+100, MC2 1307+12 and PKS 1413+135) have been reported as having radio fluxes at 5 GHz larger than 1 Jy and have  $|b| > 10^\circ$  so they should in principle belong to the

1-Jy catalogue (and therefore to the 1-Jy sample). The fact that they do not show that variability can have an effect even on radio samples.

## 2.6 Uncertain and candidate BL Lacs

Fifty objects are listed as uncertain or candidate BL Lacs. This list is quite heterogeneous. It contains BL Lac candidates from various samples and found in the literature. It also includes sources belonging to the compilation of Véron-Cetty & Véron (1993a) or of Hewitt & Burbidge (1993) but not to both. Note that the  $V$  magnitudes reported by Véron-Cetty & Véron (1993a) are actually  $B$  magnitudes if no  $B - V$  colour is given. In those cases, which include also a few miscellaneous objects, we estimate the  $V$  magnitude assuming  $B - V = 0.6$ , the mean value for BL Lacs.

## 3 STATISTICAL PROPERTIES

The BL Lac catalogue assembles sources selected in different bands with different flux limits. Therefore, detailed statistical analysis should be restricted to appropriate subsamples and not to the whole collection of objects, unless all the biases due to the different selection processes can be fully taken into account. We can nevertheless have an overview of some general properties like the distribution on the plane of the sky and the redshift distribution.

Fig. 1 shows the Aitoff projection in equatorial coordinates of the BL Lacs in the catalogue. A bias in favour of northern declinations is clearly present: out of 233 objects, 178 (i.e. 76 per cent) have  $\delta > 0^\circ$  and there are no known BL Lacs with  $\delta < -53^\circ$ . This reflects the fact that most major surveys have been done in the northern hemisphere, which has a direct influence on radio samples and an indirect influence on serendipitous X-ray samples.

Only 115 objects (or about 50 per cent of the catalogue), excluding lower limits, have redshifts, which shows how difficult it is to extract this important information from BL Lac spectra. Fig. 2 shows that the redshift distribution for the catalogue peaks at  $z \sim 0.1 - 0.2$ . Note that, apart from a BL Lac candidate at  $z = 1.715$ , the most distant confirmed object reaches  $z = 1.215$  and only four objects (plus two lower limits) have  $z > 1$ . This is in marked contrast to the redshift distribution of quasars in the Hewitt & Burbidge (1993) catalogue (see their fig. 3) and is unlikely to be due to selection effects inherent to the different sample. The redshift distributions of BL Lacs and quasars, in fact, are also quite different in complete samples: in the 1-Jy catalogue, for example (Stickel et al. 1994),  $z_{\max} \sim 3.8$  for quasars but only  $\sim 1.2$  for BL Lacs. This is probably related to the small (possibly absent or even negative) cosmological evolution displayed by BL Lacs (see e.g. the discussion in Padovani & Giommi 1995a).

The most ‘popular’ BL Lac is Mrk 421 alias S4 1101+364 alias PG 1101+385 alias 1H 1104+382 alias 1ES1101+384 alias GRO J1106+38, as it belongs to five samples: S4, PG, *HEAO*-1, Slew, and *GRO*. It is closely followed by three other BL Lacs which belong to four samples: PG 1218+304 alias EXO1218.8+3027 alias 1H 1219+301 alias 1ES1218+304 (PG, *EXOSAT*, *HEAO*-1, and Slew surveys); Mrk 501 alias S4 1652+398 alias 1H 1651+398 alias 1ES1652+398 (1-Jy, S4, *HEAO*-1, and Slew surveys);

**Figure 1.** The Aitoff projection in celestial (i.e. equatorial) coordinates of all BL Lacs in the catalogue. Note the strong bias in favour of northern declinations.

**Figure 2.** Redshift distribution for all BL Lacs in the catalogue. The hatched area indicates BL Lac candidates.

and 3C 371 alias S4 1807+698 alias 1H 1803+696 alias 1ES1807+698 (1-Jy, S4, *HEAO*-1, and Slew surveys).

As anticipated in the Introduction, a first use of this catalogue has been the extraction of all BL Lacs from the WGA catalogue to study their X-ray properties. Those results will be presented elsewhere (Padovani & Giommi 1995b).

ASCII and  $\text{\TeX}$  versions of the catalogue can be obtained on NCSA MOSAIC at the following URL: <http://itovf2.roma2.infn.it/padovani/catalogue.html>. We welcome comments, suggestions, corrections and additions, all of which should be addressed to the first author (electronic mail: padovani@roma2.infn.it).

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